

## Chapter 5: Pipe Arch Culverts With Sloping Weir Fishways

Pipes with sloping weir fishways are designed as plunging flow pools. The weirs are sized and spaced to dissipate the energy between the pools as well as maintaining a minimum flow depth and velocity for juvenile passage.

The weir plates are fully welded to the culvert or pipe. The design variables are weir spacing, weir type, and weir height. Those variables are dependent on the design flows and slope of the structure. The weirs' backwater to each other for a no jump condition during low flows and maintain resting pools for higher flows.

Inlet weirs are no longer recommended. Place the first weirs or baffle three to four feet from the inlet. The goal is to backwater flow into the natural channel coming into the pipe dissipating the approach velocity and creating a resting pool at the inlet of the pipe.

On the outlet end of the culvert an energy dissipation basin is required to backwater flow to a minimum depth of 6 inches. Twelve inches is the desired backwater depth.

A typical pipe weir will be 18 inches high on a 45-degree angle to the pipe. We have found that this sloping design is self cleaning. Brush and floating debris will pass through the pipe without hanging up.

A notch is placed in the weir. The notch allows a swim-thru channel during low flow periods and provides an attractive flow jet for movement during high flow. We have studied and constructed pipes with various notch designs. A 60-degree v notch full depth appears to be a good compromise that allows some movement of non fish species while still maintaining easy passage of juveniles between the pools. The notch is extended to the base of the pipe to allow movement during all flows. The type of notch or opening is designed to provide a minimum backwater depth to the preceding weir.



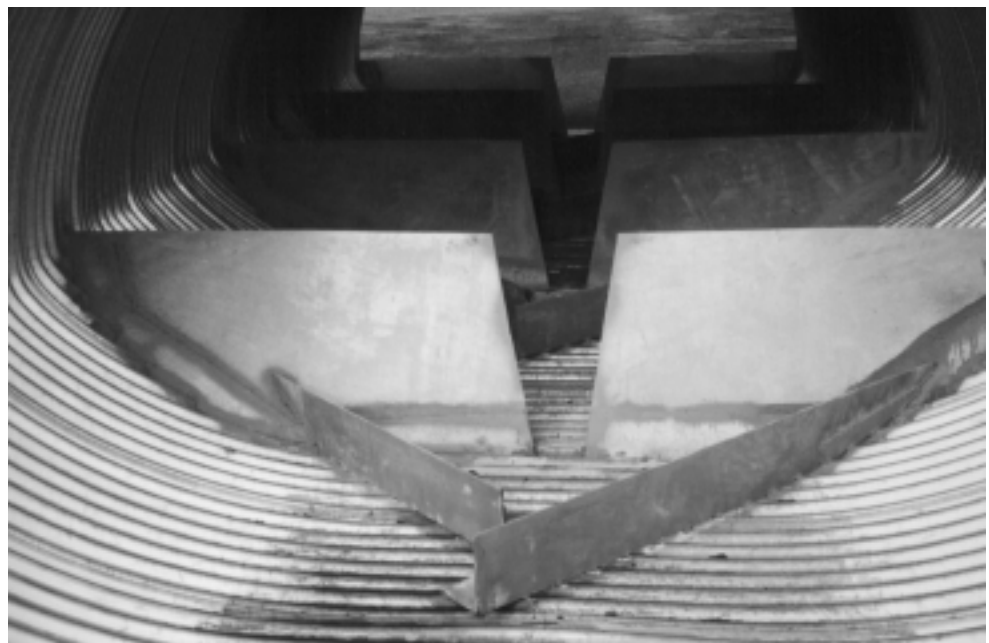
## Weir Flow Model

Flows through fishway weirs are modeled as a pool and weir fishway. When we initially began using them, we used a single weir spaced uniformly through the pipe. The weir was designed to backwater to the previous weir at low flows and still maintain a sufficient pool volume for high flow conditions.

The pipes worked well for passage of fish for both high average and low average monthly flow conditions. We achieved fish passage in culverts with grades up to 13% with that design. The design did pose a barrier to non fish species and invertebrate at the notches where there often was a short segment of pipe without gravels.

A second condition we found was that many of our pipes filled with gravels to the tops of the weirs providing the same condition as occurs with the herringbone baffle design. This condition occurred in low gradient pipes. The conclusion we were able to make is that for shallow grades using the herringbone baffle design best met our design goals. Of course during very high flow events the gravel may all recycle through the pipe but we have no way to ascertain if that is the case or not.

A goal is to collect some substrate between the weir but not enough to prevent their effective operation during high fish flow. Several weir models were tested. Baffles were installed between the weirs to back up flow for low flow fisheries' movement and higher weirs are installed to create pools for high flow fish movement. One design model used a V notch design as shown in the previous photo; the other was a Cippoletti notch. With the Cippoletti notch we ended the baffle one foot in front of the notch. (See photo)



Using the latter design, at the Woodward site, gravels backed first through the weirs prior to collecting behind the baffles. The Cippoletti weirs have a wider opening which helps keep the velocity low during low flows and aids in preventing blockages.

### **Designing with sloping weirs and baffles:**

The design variables are the weir spacing, height and type. The design parameters include the size of the culvert needed for the 100-year flow, the active channel width, the flow during low flow juvenile passage, the flow during high flow juvenile passage, and the high adult passage flow.

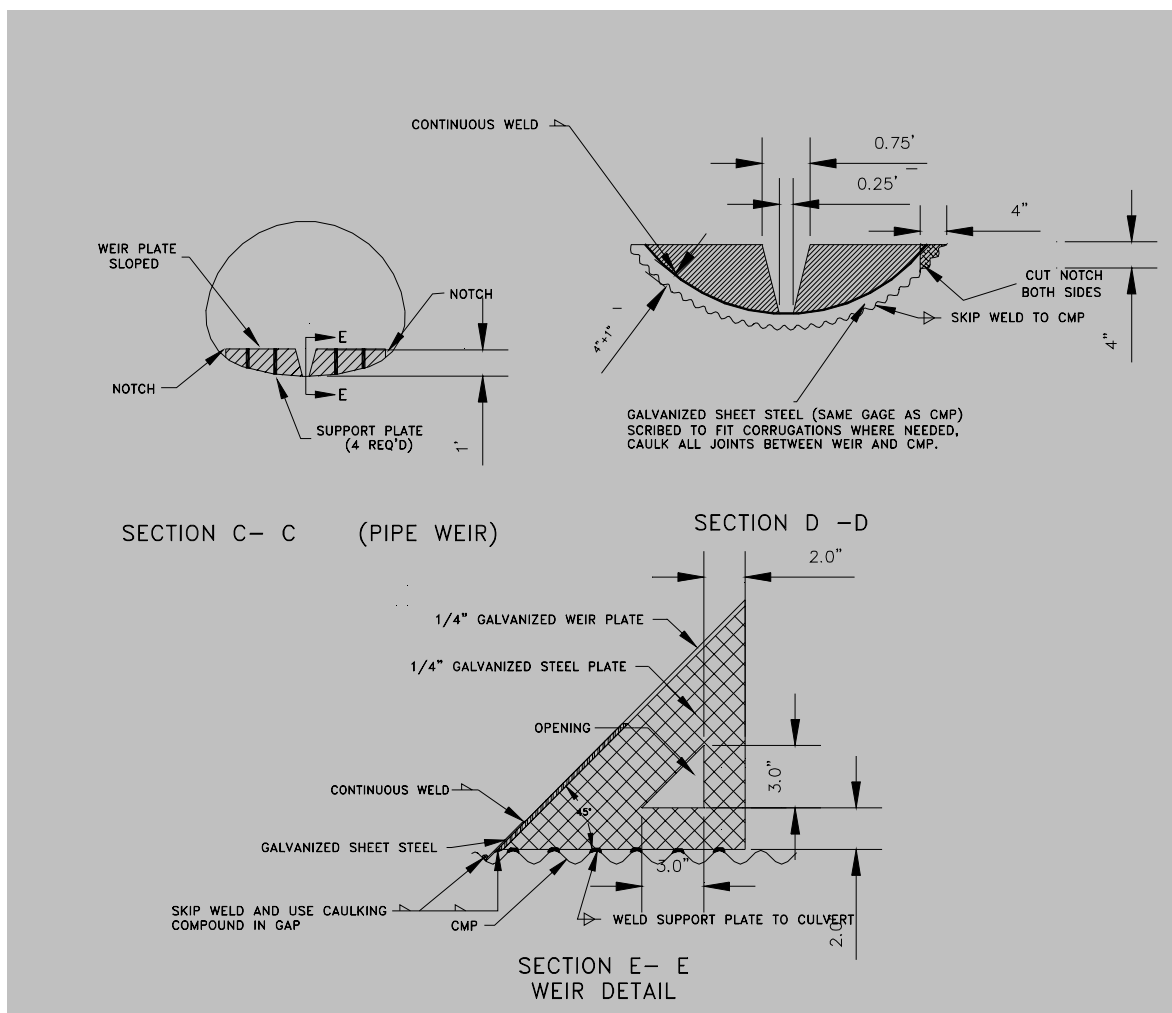
- ☺ Design for low juvenile fish passage by adjusting the baffles spacing and with between the baffles: The baffles are assumed to act as slotted weirs. The width of the slot and the spacing of the baffles is adjusted to achieve a minimum backwater depth to the weir or baffle behind it. The baffles are assumed to be watertight in this application and are fully welded or sealed to the bottom of the culvert. The baffles are also installed in a herringbone pattern to collect some substrate between the baffles and weirs.
- ☺ Design for high juvenile flow and high adult flow with the sloping weirs. Low juvenile flows are checked to verify that they will backwater to the baffles between them.

The weirs are always designed with support plates separated two feet in center allowing future retrofits to change the weir notch configuration. Flow data is included for this design in Appendix D.



## Big Log Creek Design

A new version of the weir and baffle design was recently proposed for Big Log Creek. A copy of that design is attached. The design is similar to the previous examples except holes are constructed in the weir support plates and notches are cut into the sides of the weir plates for juvenile movement. These improvements were proposed from photo studies of fish movement through culverts where juveniles were observed moving along the edge in a low velocity zone. The notches along the side will allow juveniles moving to move easily between pools. The notches in the support plate will allow juveniles to move to the center notch sheltered by the overhanging plate above. Those notches will be field checked this summer. After our monitoring we expect to modify our older installations. Complete drawings for this design are attached.



## Evaluation Criteria- culverts with fishway weirs

### Positive

1. Meet fish passage criteria except large woody debris
2. When installed correctly will minimally change channel characteristics.
3. Are often the only way to achieve passage for grades greater between 6.0% and 13%.
4. An inexpensive alternative when compared to open bottom structures and bridges.
5. On steep gradients may be the only effective way to get fish passage without having an excessively wide open bottom structure.

### Negative

1. Current designs may still restrict flow to some invertebrates.
2. Potential maintenance if weir slots become plugged. To date this has not been a problem. A maintenance plan should be included in the design.



An outlet picture of a circular pipe with weirs. This is an older design. All pipes are now constructed with pipe arches to better approximate the active channel width.

The photo below shows a culvert constructed with both weirs and baffles. The baffle is designed for low flow fish movement. The weir is designed for high flow fish movement.



Marlow  
Creek Culvert  
lower Site.  
Mark Storzer is  
pointing to the gap between the baffles. The width of that gap varies with this design.

## Hydraulic Design

Culverts designed with weirs are modeled as “pool and weir fishways.” The design objective is to provide a structure that will have velocities in the fishways plunging jet less than the fish’s burst speed and velocities in the pool low enough for resting and reorientation.

### Design Process.

1. Make a prediction of the lowest flow in the stream when fish are moving. Check design to verify that juvenile fish are able to swim between weirs without jumping and that the depth of the backwater pool is deep enough for their movement.
2. Make a prediction of the highest flow in the stream when fish are moving. Check design that fishway is operating in a stable plunging flow mode at that flow. Outside that range the fishway may be too turbulent for juvenile passage.
3. Make a prediction of the 100-year design flow: Check design that pipe has adequate size to pass the 100-year design flow. Deduct the area from the pipe taken up by the pool and weir fishway.

### Flow in pipes with fishway weirs

In a recent study under the direction of Professor N. Rajaratnam flows through a flume with weirs were described at various flows and configurations. The following definition was developed.

#### 1. Pool and weir fish-way

The construction of regular spaced weirs in a channel or flume that distributes the total head drop over the length of the facility. It is this incremental decrease in head that produces pools in between the weirs.

#### 2. Resident time

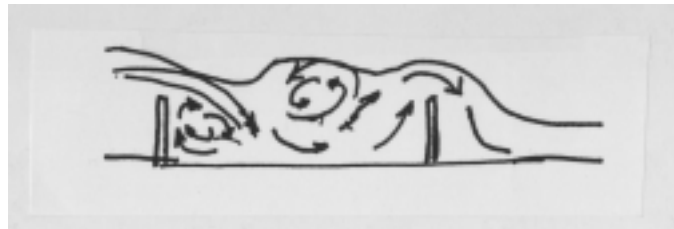
The length of time a fish will rest or reorientate themselves in the circulating pools prior to jumping or swimming to the next weir.

### 3. Flow Patterns

The pattern of water flowing over the weirs. The two dominate patterns are *plunging* and *streaming* flow. Plunging flow occurs at low discharges and streaming flow will result at high flows. Between these two ranges is a third flow defined as *transitional* flow.

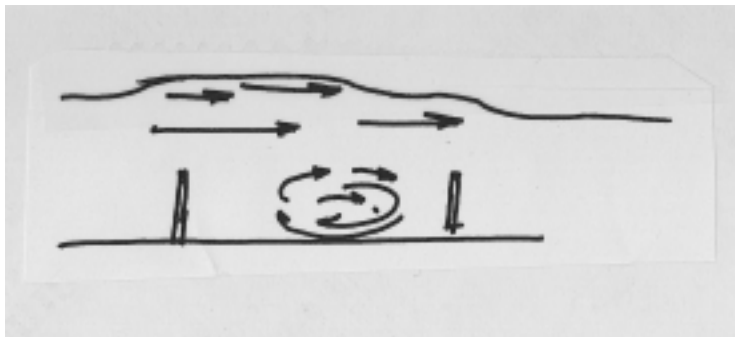
#### a. Plunging Flow

Plunging flow is quite similar to the flow patterns produced by a sharp crested weir. For this weir like type of flow there are three significant flow patterns which occur in every pool or cell. The first is the plunging jet. The second and third are caused by that diving jet. Two fully encompassing circulating cells develop. The first circulating cell is located in the nape directly beneath the plunging jet. The second significant cell was positioned near the surface immediately downstream of the point where the plunging jet poured into the pool. This flow was counterclockwise.



#### b. Streaming Flow

Streaming or skimming flow consists of a plane turbulent surface jet of water passing over the weirs while the flows in the cells between the weirs are rotating in a singular direction due to the entrained flow from the surface jet. The turbulent shear stress interfaces which reside between the rotating cells and the surface jet is a key component to this system. It is this shear stress that dissipates the potential energy, prevents the flow from accelerating, and permits steady uniform flow to occur.





## **Pool Fish Capacity:**

The capacity of a pool to hold fish. The pool volume for fish is about 0.4 cubic feet per pound of fish. When designing fishways for dams this is a significant calculation. For mountain streams, where the numbers of fish moving at one time is small that calculation is normally not done.

## **Energy Dissipation Factor**

This equation was initially the most significant variable in my opinion for determining if a pool had adequate size for flow. The premise is that a pool must have enough volume to dissipate the energy of the water entering the pool. This prevents turbulence and aeration to the point that resting area is provided. The typical energy dissipation criterion for salmon and steel head is based on a maximum energy dissipation of 4 pounds of energy per second per cubic foot of volume.

The following equation was developed to satisfy that premise. For plunging flow to occur the following condition must be satisfied.

$$(Q \times 62.4 \times H) / \text{vol.} < 4.0 \text{ to } 5.0$$

Q= flow in cfs

H= head change between pools

Vol.= Volume of water in pool

The most recent experiments by Rajaratnam however indicate that this relationship may be very conservative. He developed formulas for stable plunging flow that significantly extended the range of flows beyond the earlier equation above.

Using the experimental data from his thesis and the previous formulas, the design program used for this model was upgraded. Juvenile passage is still modeled against the formulas above but adult passage is checked against Rajaratnam values.

I also compared his flow for stable plunging flow against those in the equation above and found another relationship. The relationship I noted was similar to the one above but includes an additional variable: The percent of backwater and the type of fishway being evaluated. I included percent backwater in the design program to assist in developing a useful formula in the future.

This past winter, flow data was gathered on the Sloping Weir Fishway with Baffles and the herringbone baffle fishway. Copies of those results are included in the project summaries under Marlow Creek.